RECOMMENDATIONS FOR OPERATIONAL WATER QUALITY MONITORING AT CAGE CULTURE AQUACULTURE OPERATIONS

Report to Northern Region by:

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1. BACKGROUND

The Manitoulin area of Lake Huron's North Channel is the site of seven active aquaculture operations, two recently active operations, and two start-up operations. As well, the potential has been identified for expansion at existing sites. An extensive literature exists on the potential environmental impacts of aquaculture operations on marine and freshwater systems based on the historic growth of the industry in Europe, the U.S., and on the Canadian marine coasts. Nutrient pollution (eutrophication) and the corresponding potential for algal blooms, oxygen depletion, and degradation of benthic habitat in the vicinity of open cage operations with no waste collection system and limited flushing are the principle water quality issues. Other water quality issues identified in the literature include release of bacteria, pesticides, antibiotics, and non-native species.

During June 1998 a multi-agency workshop was held at which monitoring requirements were discussed and advocated by MOE to representatives from MNR, and OMAFRA. The potential for water quality impacts from open cage operations was identified as depending in part upon site-specific characteristics according to three general types of sites:

Type 1. enclosed (lake like) basins with limited flushing;

Type 2. partially exposed sites having good epilimnion/metalimnion flushing but limited or no hypolimnion exchange; and

Type 3. exposed locations where the hypolimnion is also well flushed.

It was recommended that siting considerations and operational monitoring requirements be tailored according to the type of site. Monitoring in 1998 and 1999 has established that for the Manitoulin area Type 2 sites can be defined bathymetrically as sites where the 14 m -16 m depth contour is locally bounded, and Type 3 sites as where this depth contour is not locally bounded.

During 1998 an extensive monitoring effort by MOE Northern Region (MOE/NR) was initiated at nine sites, augmented at two locations by MOE Environmental Monitoring and Reporting Branch (MOE/EMRB). MOE/NR also developed and distributed interim recommendations for self-monitoring by aquaculture operators (MOE 1999). During the spring of 1999 the Sudbury and North Bay District Offices of MOE/NR requested that MOE/EMRB undertake a follow up study on the effects of cage aquaculture operations on water quality at in the Manitoulin Island area and at Parry Sound (Depot Harbour). The resulting 1999 MOE water quality study was undertaken by MOE/NR and MOE/EMRB to provide up-to-date information upon which to base revised recommendations to MNR concerning water quality monitoring and the interim regulation of open cage aquaculture operations.

A need to develop and pursue multi-year collaborative research was also proposed during 1999 by a consortium of government, industry, and academic groups which include the MOE Dorset research facility, NWRI at Environment Canada, MNR, OMAFRA, Experimental Lakes Area, Department of Fisheries and Oceans (DFO), University of Guelph, and Ministry of Northern Mines and Development. Given the longer term timetable for results and recommendations from this more protracted research effort, a multi-party technical "Team 1" comprising representatives from MOE, MNR, OMAFRA, University of Guelph, Environment Canada, industry representatives, and cottagers (GBA) was formed and held three meetings (9 December 1999, 20 January 2000, and 21 September 2000) to discuss and seek scientific consensus on appropriate interim monitoring and modelling protocols and the corresponding application of the results. The goal of "Team 1" was to provide advice that would allow the interim management of the industry in a manner acceptable to all concerned parties while allowing the research community sufficient time to explore issues in greater detail.

A draft report containing a summary of 1999 data and recommendations for water quality monitoring was released for review by the multi-party Technical Team in April 2000 and comments were received from both industry representatives and cottagers (Georgian Bay Association), as well as from participating government agency staff. Subsequent drafts of the monitoring recommendations were released for review by the Technical Team in August 2000, and January 2001and comments received during the spring of 2001 have been incorporated into this version of the monitoring recommendations.

2. RECOMMENDATIONS FOR OPERATIONAL WATER QUALITY MONITORING

Recommendation 1: Regional Background Water Quality

MOE/EMRB results from five routinely monitored MOE index/reference sites in the nearshore waters of North Channel (Lake Huron) and Georgian Bay will be used to provide regional background water quality data for the area. The sites are located at North Channel (Eagle Island), French River, Parry Sound, Pleasant Island (Parry Sound), and Moon Island.

Rationale:

The MOE network of index/reference stations is designed to provide information on where and how water quality conditions are changing over time by periodically monitoring a suite of environmental indicators. The comprehensive sampling effort associated with this activity includes spring, summer, and fall sampling for various "conventional" water quality indicators along with physical measurements such as thermal and optical profiles of the water column. These sites were sampled in both Georgian Bay and the North Channel in 1996. In 1999 the North Channel was sampled again as part of the "Lake Superior Intensive Year" and will be repeated as part of the MOE regular cycle. Georgian Bay will be sampled again in 2002 as part of the "Lake Huron Intensive Year" and these sites will also be re-sampled as part of the MOE regular cycle.

The fundamental intent of monitoring at these reference sites is to characterize the general background in the open area of Georgian Bay and North Channel. These data are not designed to document either short-term temporal variability or local spatial variability in specific water quality parameters such as total phosphorus (TP). Although this variability in TP undoubtedly occurs, the prime MOE interest is to assess whether this area has natural background concentrations less than 10.0 $\mu g\ L^{-1}$ when interpreting Policy 1 and Policy 2 from MOE 1993: *Water Management Policies, Guidelines, Provincial Water Quality Objectives* (usually referred to as the "Blue Book") [1]. Existing MOE data consistently demonstrate median and mean TP concentrations for this area below the MOE quantification limit of 10.0 $\mu g\ L^{-1}$, ranging as low as the current absolute limit of detection which is 2.0 $\mu g\ L^{-1}$. These data also demonstrate no natural long-term increasing trend for total phosphorus (TP) at sites removed from the immediate influence of tributary mouths or urban/cottage/marina development. Variability attributable to these influences is not being incorporated into the background comparison for fish farms since the overall MOE goal is to ensure that any "Policy 2" areas not currently meeting the 10.0 $\mu g\ L^{-1}$ criterion are diminished wherever possible. Sites which are already situated in an area with pervasive background concentrations greater than the characteristic, regional value of < 10.0 $\mu g\ L^{-1}$ (such as Wolsey Lake) will require special consideration and consultation.

The use of these standardized data at these locations will preclude any concern that fish farm operations may influence their own standard for comparison. Industry concerns regarding the inequity of imposing restrictions on aquaculture operations as the result of shifts in local "background" concentrations attributable to anthropogenic influences other than fish farms are legitimate, however this should not be addressed by allowing further degradation in water quality. Instead, we recommend that any evidence of such a situation be used to promote discussion between MOE and potentially responsible parties. Where necessary this should lead to changes in conditions of approval to all relevant water users, not just aquaculture operators.

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[1] *Policy 1*: In areas which have water quality better than Provincial Water Quality Objectives (PWQOs), water quality shall be maintained at or above the Objectives;
Policy 2: Water Quality which presently does not meet the PWQOs will not be degraded further and all practical measures will be taken to upgrade the water quality to the Objectives;

Recommendation 2: Location of Water Quality Sampling Stations

Permanent water monitoring stations should be established by aquaculture operators at the four corners of offshore cages (i.e. not directly accessible from shore), or at the midpoints of the three open sides at cages anchored near the shore. These stations should be situated 30 m (100 feet) from cages, or at the perimeter specified in the MNR site tenure agreement (currently a Land Use Permit), whichever is less [2]. In addition, two local reference stations will be established on a site-by-site basis as a means of assisting in the interpretation of near-cage water quality data. These reference sites should cover potential "upstream" and "downstream" conditions relative to fish cages, and should be established in similar depths to fish cages (e.g. the same depth as the cage mid-point), and have a similar exposure, orientation, and circulation as the cage site. Depending upon site-specific circumstances, a proximal deep (>20 m) station may also be established for temperature and dissolved oxygen (DO) monitoring only (see Recommendation 4*).*

Rationale:

Existing data demonstrate that water quality gradients occur close to aquaculture operations and that variability increases with proximity to cages. A distance of 30 m for near-cage stations represents a good compromise for near-cage sites given the variability encountered closer to the cages, as well as the uncertainty associated with positioning and changes in the deployment and orientation of individual fish cages. Setting the maximum distance for near-cage sampling at the perimeter specified in the site tenure agreement issued by MNR ensures that continued expansion of an operation does not automatically provide unlimited expansion of the corresponding operational zone with respect to MOE water quality objectives.

Although regional background conditions (as demonstrated by MOE data) will be used to set the trigger limit for phosphorus (see *Recommendation 3*), data from the two reference sampling stations will be crucial to the interpretation of water clarity (Secchi depth) data and will help establish the presence of other natural and anthropogenic nutrient sources which need to be taken into consideration by MOE if the trigger limit for phosphorus is exceeded.

[2] This provision requires that such a boundary be specified in the site tenure agreement either as a georeferenced centre point and radius, or as a series of georeferenced boundary markers.

Recommendation 3: Phosphorus Sample Collection and Data Analysis

A minimum of eleven water quality samples should be collected at each of the three or four near-cage stations and the two reference stations: three during spring turnover, five during the summer thermally stratified period, and three during fall turnover. The spring samples should be obtained at five-day to seven-day intervals following ice-out (typically during April), the summer samples at approximately monthly intervals during the period late-May through mid-October, and the fall samples at at five-day to seven-day intervals in the late fall (typically during late-October/early-November). These samples should be depth-integrated over the depth of cages (typically 8m to 12m) and analyzed at a CAEL accredited laboratory for total phosphorus (TP) with a minimum detection limit of 2 $\mu g\ L^{-1}$, and a quantification limit of 10 $\mu g\ L^{-1}$ or better (the current MOE quantification limit for routine analysis at the Rexdale laboratory).

The near-cage phosphorus data will be partitioned and median phosphorus concentrations will be computed as follows: (1) spring data (n = 9 or n = 12); (2) fall data (n = 9 or n = 12); and (3) ice-free seasonal data (n = 33 or n = 44). Spring results should be reported within 30 days of the last sample collection date. Except where noted under "trigger limits and actions" summer and fall results should be compiled and reported by the end of the calendar year.

Trigger Limits and Actions:

1. Spring Data

If the spring median concentration of phosphorus is **greater than or equal to** 10 $\mu g\ L^{-1}$ the operator will be required to:

(1) Undertake an operational audit and submit an abatement plan identifying the steps that will be taken to increase the efficiency of the operation and to result in a net decrease in operational scale (feed quota) from the previous operating season;

(2) Consult with MOE to increase the frequency of summer and fall phosphorus sampling;

(3) Confirm the absence of nuisance algae related concerns with adjacent water users and property owners at the "upstream" and "downstream" boundaries specified in the site tenure agreement [3].

2. Fall Data

If the fall median concentration of phosphorus is **greater than or equal to** 10 $\mu g\ L^{-1}$ the operator will be required to:

(1) Undertake an operational audit and submit an abatement plan identifying the steps that will be taken to increase the efficiency of the operation and to freeze the operational scale (feed quota) for the subsequent operating season;

(2) Consult with MOE to increase the frequency of phosphorus sampling in the spring, summer, and fall of the subsequent operating season; and

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[3] This could be achieved by deploying submerged artificial substrates for assessment of periphyton growth and comparing the total seasonal periphyton biomass at these locations with similar substrates deployed at reference sites. Periphyton growth on submerged artificial substrates has been shown to be an accurate descriptor of phytoplankton response to nutrient enrichment (Smoot *et al.* 1998) and there are a number of references available to guide the design and deployment of these sampling devices and the corresponding data interpretation (A.P.H.A. 1992, Porter *et al.* 1993, Saravia *et al.* 1999, Barbour *et al.* 1999). Additional assessment of this approach is currently being undertaken by MOE.

(3) Confirm the absence of nuisance algae related concerns with adjacent water users and property owners at the "upstream" and "downstream" boundaries specified in the site tenure agreement .

3. Ice-free Seasonal Data

If the ice-free seasonal median concentration at the 30m near-cage stations is **greater than or equal to** 10 $\mu g\ L^{-1}$, the operator will be required to:

(1) Undertake an operational audit and submit an abatement plan identifying the steps that will be taken to increase the efficiency of the operation and to freeze the operational scale (feed quota) for the subsequent operating season;

(2) Consult with MOE to increase the frequency of phosphorus sampling in the spring of the subsequent operating season; and

(3) Confirm the absence of nuisance algae related concerns with adjacent water users and property owners at the "upstream" and "downstream" boundaries specified in the site tenure agreement

Rationale:

The MOE "Blue Book" policy for interpretation of the relationship between TP enrichment and the potential for nuisance concentrations of algae is generally interpreted to require an estimate of the average, ice-free seasonal concentration of TP and data from the three or four proximal stations will allow this estimation (using 33 or 44 data points respectively). However, the "Blue Book" also acknowledges that this is an interim approach due to the complexity of the relationship between concentrations of TP and the production of nuisance algae in lakes. The "Blue Book" suggests that the interim objectives be considered as general guidelines which should be supplemented by site-specific studies.

Existing MOE data reinforce the obvious need to recognize that the distribution of results across the ice-free season can provide important information that should not be overlooked when interpreting the data in the context of aquaculture operations. Although results from individual sampling stations and individual sampling days should not be interpreted in isolation, elevated spring turnover results will be of greatest concern since this will clearly signal the potential for an early season algal bloom and will cast doubt on the suitability of the location for aquaculture operations at the current scale. Elevated fall turnover results will be of next greatest concern since this will demonstrate a cumulative effect which remains apparent even after late fall mixing with hypolimnetic water and which may carry over into the spring of the following season.

There are a number of limnological and statistical factors to consider when recommending the best approach to sampling for estimation of ice-free average TP concentrations in a water body, particularly during the summer stratified period. Although it would be scientifically preferable to sample separately above and below the thermocline at a sufficient number of sample depths to estimate a concentration profile (i.e. at four or five depths), the goal here is to provide a reasonable estimate of average conditions at a particular location on a particular date as part of an overall seasonal average. For this reason we suggest that a sample integrated over the depth of cages will suffice, despite the potential for this to be biased low or high during the summer stratified period. The additional burden of sample collection and analysis that would be required in order to estimate depth, or volume, weighted mean TP concentrations based on concentration profile results is hard to justify given the use of the results. In cases where enhanced algal productivity has scavenged TP to the hypolimnion through settling of phytoplankton, and where ice-free average conditions may be biased on the low side, the separate scrutiny of fall turnover results will provide a safety net (i.e. since TP-enriched hypolimnetic water will be mixed back into the

water column at fall turnover).

Skewed samples can affect the power and significance of directional (or one-tailed) tests using arithmetic means, and since the TP concentration data near fish cages may exhibit positive skewness resulting from a few relatively elevated concentrations, this would require an appropriate data transformation to satisfy assumptions of normality. Since the overall goal here is to characterize seasonal average concentrations in order to flag the potential for nuisance-concentrations of algae, the use of the median [4] as a measure of central tendency is recommended as a way of simplifying the data analysis, especially since it is possible to estimate a 95% confidence interval about the median [5]. Although these data can be used to compute a median and confidence interval which can in turn be used to apply a statistically based comparison with the trigger limit (i.e. a one-tailed test at a given probability for a Type 1 error) it is important to note the limited sample size (n = 9 or n = 12) associated with spring and fall data reduces the power of the median-based one-tailed test to the point where the probability of a Type 2 error becomes unacceptably high. For this reason we recommend that application of a one-tailed test be limited to data sets where n >30. This would include the ice-free seasonal data set (i.e. where n = 33 or n = 44) but not the spring data set or the fall data set.

The decision to set the TP trigger concentration at **greater than or equal to** 10 $\mu g\ L^{-1}$ is a slight departure from previous recommendations which have set it at greater than 10 $\mu g\ L^{-1}$ and is an arbitrary means of compensating for the fact that positively-skewed data will tend to yield a sample median TP concentration of less than 10 $\mu g\ L^{-1}$ where the arithmetic mean is greater than 10 $\mu g\ L^{-1}$.

A TP trigger limit based on "*background plus*", rather than an arbitrary concentration of 10 $\mu g\ L^{-1}$, is theoretically superior in that preserves a more natural range of conditions and protects areas with the lowest natural background concentrations from absorbing the greatest relative impact. This approach is under consideration by MOE and MNR for application to inland lakes but is not yet established, nor is it contemplated for the Great Lakes. Notwithstanding the uncertainty regarding its general applicability in the Great Lakes, a practical concern in the case of monitoring at fish farms is the detection limit for routinely-available TP analyses at the MOE laboratory (or private sector laboratories) which cannot provide high-confidence quantification of TP at concentrations below 10 $\mu g\ L^{-1}$. This will be extremely problematic for a *"background plus"* approach since background concentrations in these waters are typically reported from the MOE laboratory in the range of 4 $\mu g\ L^{-1}$ to 6 $\mu g\ L^{-1}$ with the *caveat* that results are "trace only and should be interpreted with caution". Until a routine method yielding a quantification limit an order-of-magnitude below current levels becomes widely available the *"background plus"* approach cannot be adopted. Clearly, if a particular background concentration is currently being reported as 4 $\mu g\ L^{-1} \pm 2\ \mu g\ L^{-1}$ the data quality is not sufficient to stipulate a 50% increase as the permitted difference (and a 5 $\mu g\ L^{-1}$ increase would be equivalent to imposing a 10 $\mu g\ L^{-1}$ trigger limit).

This widespread limitation on TP data quality at concentrations of less than 10 $\mu g\ L^{-1}$ also supports the use of a median statistic rather than the mean, since it is possible to compute a median using the semi-quantitative data at concentrations below 10 $\mu g\ L^{-1}$ by ranking them together in one class labelled "less than 10 $\mu g\ L^{-1}$". Pooling the data in this fashion would also make explicit the potentially spurious accuracy of means computed using concentrations in the range from 2 $\mu g\ L^{-1}$ to 10 $\mu g\ L^{-1}$.

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[4] The median of a set of measurements is defined to be the middle value when the measurements are arranged in order of magnitude. In small sets of measurements with an even number of observations, the median will be the average of the two middle values when the measurements are arranged in order of magnitude.

[5] The recommended approach is that outlined in Zar (1984) which outlines a procedure for estimating the confidence interval of the median by considering the binomial distribution (Section 8.8, p. 113).

It is not our intention to invoke analytical data quality restrictions associated with TP as a reason for relaxed vigilance in connection to potential water impacts resulting from cage aquaculture operations. The MOE Laboratory Services Branch has been requested to develop and sanction a method for ultra low level TP analysis which will eventually allow a transition to a "*background plus*" approach, should the need arise. In the interim, the recommended trigger limit of 10 $\mu g\ L^{-1}$ TP at $\leq$30 m from fish cages should be viewed in the context of potential concerns related to increases in TP as well as other monitoring recommendations.

The principal water quality concerns associated with elevations in TP stem from the expected increase in algal productivity which has the potential to cause aesthetic problems, and which can lead to increased hypolimnetic oxygen consumption as the result of algal settling and decomposition. Organic enrichment of sediment in areas affected by algae blooms may also occur leading to increased sediment oxygen demand and resulting in the loss of sensitive benthic macroinvertebrates such as mayflies. Direct monitoring of dissolved oxygen is the best means of assessing the influence of fish farm emissions of TP and ammonia on the oxygen status of local water quality, and effects on sediment can also be independently assessed.

This leaves the relationship between TP and aesthetic degradation as the principal reason to track localized TP concentrations for and comparison with a trigger limit. There is no simple cause-effect relationship between **individual** water quality observations of TP concentrations greater than 10 $\mu g\ L^{-1}$ and increased concentrations of chlorophyll (as an indicator of algae) or decreased water clarity. These patterns emerge once these intrinsically variable data are aggregated. Since other measures of aesthetic degradation are also part of the recommended monitoring package, the currently recommended approach to separate assessment of (a) spring, (b) fall, and (c) ice-free seasonal TP concentrations is considered to be sufficient as an interim means of flagging the potential for aesthetic degradation.

Recommendation 4: Water Clarity Sample Collection and Data Analysis

High frequency (at least weekly) sampling for surface water clarity (Secchi depth and colour) should be undertaken at the three or four near-cage stations and the two local reference stations at all fish cage operations during the ice-free season. Results should be compiled and reported according to the schedule established for TP water quality results.

Trigger Limit and Actions:

If the ice-free seasonal median water clarity (expressed as Secchi depth [6] with a precision of 0.2 m) is observed to be 10% less than the seasonal median for the two local reference locations (allowing for a reading error of ±0.1 m), then the operator will collate and provide a summary of wind, weather, and wave conditions corresponding to the sampling episodes. Depending upon the results of this data analysis, and a comparison with corresponding TP data the operator may be required to add opportunistic chlorophyll sampling (with the assistance of MOE) to the list of monitored parameters during the following field season during episodes of reduced water clarity. The criteria defining these episodes will be established through examination of the high frequency data.

Rationale:

Whether or not analysis of Secchi depth data reveals a statistically significant difference between near-cage and reference conditions, they will be of considerable assistance in the interpretation of other water quality information. Secchi depth monitoring provides an easy, well-established means of observing changes in surface water quality and is particularly well suited to documenting the effects of nutrient enrichment and enhanced algal productivity, provided the sampling frequency is high enough. Reporting of low water clarity observations and associated weather conditions will allow an assessment of possible causes, and will make it possible to develop a site-specific understanding of the normal range of conditions, versus those attributable to algal blooms. Opportunistic sampling for chlorophyll if the data provide evidence that episodes of reduced water clarity were potentially attributable to algae (e.g. no apparent correlation with storm conditions) will provide a direct means of elucidating the relationship between algal blooms and increased turbidity. Sampling protocols and arrangements for chlorophyll analysis will be developed in consultation with MOE.

Once operators have some experience with applying the routine, standard protocol for generation of Secchi depth data, they may find it a helpful means of monitoring their operations quite apart from its potential to alert MOE to algal blooms near fish cages. It appears to have the potential to be used as a tool for assessing the efficiency of feeding operations, and could provide instant feedback on the relationship between water quality in the immediate vicinity of fish cages and standard operating procedures.

[6] Instructions on the construction and use of a Secchi disc for measuring water clarity and colour will be provided to operators upon request.

Recommendation 5: Temperature/Dissolved Oxygen Sample Collection and Data Analysis

Temperature and dissolved oxygen (DO) results should be recorded at 1 m intervals at stations with depths of ≤20 m, and at 2 m intervals at stations in depths greater than this. For "Type 1" and "Type 2" sites, temperature profiling should be undertaken weekly at the deepest of the three or four near-cage water quality monitoring stations immediately following ice out. At some locations, an additional "proximal deep" sampling location will also be established. DO profiling at these stations should be undertaken at monthly intervals after ice out until temperature profiles indicate stratification has occurred, after which the profiling frequency should be increased and made concurrent with the weekly temperature profiling. Monthly temperature and DO profiling will suffice at "Type 3" site water quality monitoring stations. Results should be compiled and reported according to the general schedule established for water quality data except when observed DO concentrations fall below 54% saturation or 6 mg L^{-1} (see below).

Trigger Limit and Actions:

All observed DO concentrations of less than 54% saturation or 6 mg L^{-1} at either of the near-cage or proximal water monitoring locations will be immediately reported to MOE and MNR. The default consequence of this situation will be to maintain a regime of restricted, subsistence feeding pending the results of twice-weekly follow up profiling which will be triggered by this condition. Continued observation of DO concentrations less than 54% saturation or 6 mg L^{-1} will lead to a reduction in the site's operational scale (or feed quota) for the subsequent operational season. Pending discussion with MNR regarding the loss of cold water fish habitat, it may also require the development of a benthic sampling program sufficient to estimate the extent of any impairment to the benthic habitat.

Since hypolimnetic DO depletion provides direct evidence of enhanced oxygen consumption, DO concentrations of less than 54% saturation or 6 mg L^{-1} will also trigger a requirement to include total ammonia, as well as TP, for laboratory analysis of water quality samples.

Rationale:

The observation of hypolimnetic DO depletion following stratification at monitoring stations near "Type 1" and "Type 2" sites indicates a condition which may be irreversible until fall turnover replenishes deep water DO concentrations, regardless of any abatement action at the fish farm. The best that can be achieved is to ensure that the condition does not occur during the following season, and for this reason we suggest that the onus be on the operator to justify why a reduction in operational scale (or feed quota) not be imposed as the best means of achieving this goal.

The observation of hypolimnetic temperatures significantly greater than 10 ^{o}C may suggest that cold water fish habitat criteria are unreasonably stringent, but this must be weighed against the fact that DO concentrations of less than 47% saturation or 4 mg L^{-1} are also indicative of stress to warm water fish species and sensitive benthic macroinvertebrates. The direct observation of benthic macroinvertebrate community structure will assist in the interpretation of the biological significance of hypolimnetic DO depletion.

Loss of hypolimnetic DO is the most critical biological stress potentially associated with fish farming, and can be avoided by siting cages in "Type 3" areas (where the hypolimnion is well mixed), as well as by incorporating fish manure collection and treatment systems once they become commercially feasible. Although un-ionized ammonia concentrations are not expected to approach the PWQO, MOE data indicate that total ammonia is a good conservative tracer of "effluent" from aquaculture operations and hence the requirement for total ammonia data is justified as a means of exploring the potential for mitigation of DO depletion through reduction in the direct oxygen demand associated with ammonia nitrification.

Recommendation 6: Sediment Sample Collection and Data Analysis

Sediment sampling should be undertaken at the "upstream" and "downstream" boundaries specified in the site tenure agreement and at the two local reference sites. At a minimum, this sampling should be undertaken the year prior to any renewal of, or revision to, an existing aquaculture licence, or site tenure agreement. The precise sampling location(s) will be determined independently for each aquaculture operation based on examination of local bathymetry and prevailing current patterns; the goal will be to assess sediment quality at the boundary of the area occupied by the operator while making allowance for local sediment depositional factors. Sampling will occur once in duplicate during the May samplig period and once in duplicate during October with samples being analysed for particle size (%> 63 $\mu g\ g^{-1}$) and nutrient status including total phosphorus (TP), total Kjeldahl nitrogen (TKN), total organic carbon (TOC) at a CAEL accredited laboratory. Results should be compiled and reported according to the schedule established for water quality TP data.

Trigger Limit and Actions:

If the data satisfy assumptions of normality, the mean nutrient (C, N and P) data at the boundary of the site tenure agreement (four samples at two stations) will be compared against the local reference station data (also having n = 8) using an appropriate t-statistic (e.g. $\alpha \leq 0.05$). If assumptions of normality are not satisfied then a non-parametric (distribution-free) comparison will be made. If nutrient concentrations in sediment at the boundary of the site tenure agreement significantly exceed those at the local reference stations then the operator will be required to undertake an operational audit and submit an abatement plan leading to a reduction in the site's operational scale (or feed quota) for the subsequent operational season. Pending discussion with MNR regarding the loss of cold water fish habitat, it may also require the development of a benthic sampling program sufficient to estimate the extent of any impairment to the benthic habitat.

Rationale:

Concerns have been expressed regarding the potential for long-term, incremental effects on the aquatic ecosystem in the vicinity of fish cages, even for sites which do not exhibit direct evidence of oxygen depletion or nuisance algae. Experience in other jurisdictions and preliminary results of sediment sampling near fish cages in 1999 suggest that it would be prudent to include a monitoring component capable of detecting possible cumulative effects on sediment, and hence benthic habitat, before these effects become observable in the water column. Observed concentrations of TP, or TKN, or TOC at the boundary of the site tenure agreement which exceed those at appropriately chosen reference sites will provide clear evidence of a sediment "footprint" which is larger than the area in which they are licensed to operate and this will, in turn, provide evidence that the operational scale exceeds the carrying capacity of this licensed zone.

Nutrient enrichment of sediment is generally a concern because of potential impacts on sensitive benthic species or the potential for re-mobilization of phosphorus from the sediment into the overlying water column under the reducing conditions associated with severe hypolimnetic oxygen depletion (this latter concern will tend to occur in situations where DO and temperature profiling have already flagged a problem and is considered of secondary significance). The *Guidelines for the Protection and Management of Aquatic Sediment Quality in Ontario* (MOE 1993) were designed to be consistent with the "Blue Book" and are intended to protect both benthic and pelagic aquatic life. "Severe Effect Levels" (SELs) have been empirically determined for various parameters as corresponding to those concentrations which *"... would be detrimental to the majority of benthic species"* and have been set for TOC, TP and TKN at 10%, 2.0 mg g^{-1}, and 4.8 mg g^{-1} respectively.

We recognize that sediment chemistry data should be used as a screening tool in conjunction with some means of biological assessment, such as identification and enumeration of benthic macroinvertebrates. It

has been argued by some that use of a benthic index based on a rapid assessment approach followed by sediment chemistry assessment is a superior screening tool since it starts by observing a biological effect and then attempts to discern possible chemical cause-effect relationships. Although this is true in theory, benthic indices do not work well as "pass/fail" trigger limits due to the inherent variability in the results, and the difficulty in establishing a suitable means of quantifying the comparison with suitable reference data. For this reason, we are recommending that observation of TOC, or TP, or TKN sediment concentrations of at the boundary of the site tenure agreement which exceed those at appropriately chosen reference sites is a practical means of flagging whether the aquaculture operational "footprint" extends to the boundary of the site tenure agreement. This condition would provide clear evidence of a sediment "footprint" which is larger than the licensed area for a given aquaculture operation and will, in turn, provide evidence that the operational scale exceeds the carrying capacity of the licensed zone. This finding is considered to be sufficient to require serious modification of operational practices.

It has also been suggested that metals analysis be included in the sediment assessment since fish feed is enriched with metals such as copper, iron, manganese and zinc (G. Cole, *pers. comm.*, National Research Council 1993) resulting in fish manure which exhibits some metal enrichment relative to background sediment concentrations (Naylor *et al.* 1998), and metal-enrichment in sediment beneath fish cages where the fish manure accumulates. Data collected by MOE near fish cages and beneath fish cages confirms the presence of elevated concentrations beneath fish cages, but provides no evidence of potentially harmful concentrations at stations 20m to 50m from the cages. The potentially toxic concentrations of metals which may be observable in the fish manure directly beneath fish cages also co-occur with extremely high nutrient concentrations which by themselves would be expected to have a significant effect on sensitive macroinvertebrates inhabiting this sediment. Although metals enrichment may have some possibilities as a tracer further from the cages, it is apparent that the nutrient enrichment will co-occur with any metals enrichment and will function as an adequate tracer of the aquaculture operational "footprint" without the need for additional routine metals analysis on sediment samples.

Recommendation 7: Evaluation and Modification of Monitoring Requirements

An annual review of monitoring requirements should take place based on the accumulated data and findings from the research community. Holding this review during the winter will allow consideration of the previous season's data and will allow any refinements to the monitoring requirements to be reflected in the following season's monitoring.

Rationale:

The primary challenge facing "Team 1" has been to reconcile the disparate concerns of industry and cottage association representatives, many of which relate to the current and proposed regulatory framework for the industry, while recognizing that the mandate of the technical team has been limited to science-based issues. Given the ongoing research activity, and continuing MOE development of a near field dispersion model for assessing the assimilative capacity at Type 2 and Type 3 sites, it is apparent that there will remain a need to periodically assess the utility and effectiveness of monitoring at aquaculture operations.

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